National Aeronautics and Space Administration

# Using Optical Measurements to Characterize the Orbital Debris Environment in GEO

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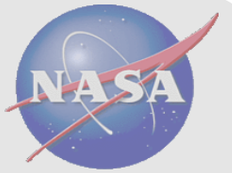
# Agenda

- **Orbital Debris Engineering Model (ORDEM) Background**
- **Building/Validating the GEO Population for ORDEM 3.1**
- **Eugene Stansbery Meter-Class Autonomous Telescope (ES-MCAT) Overview**

# ORDEM – An Engineering Model

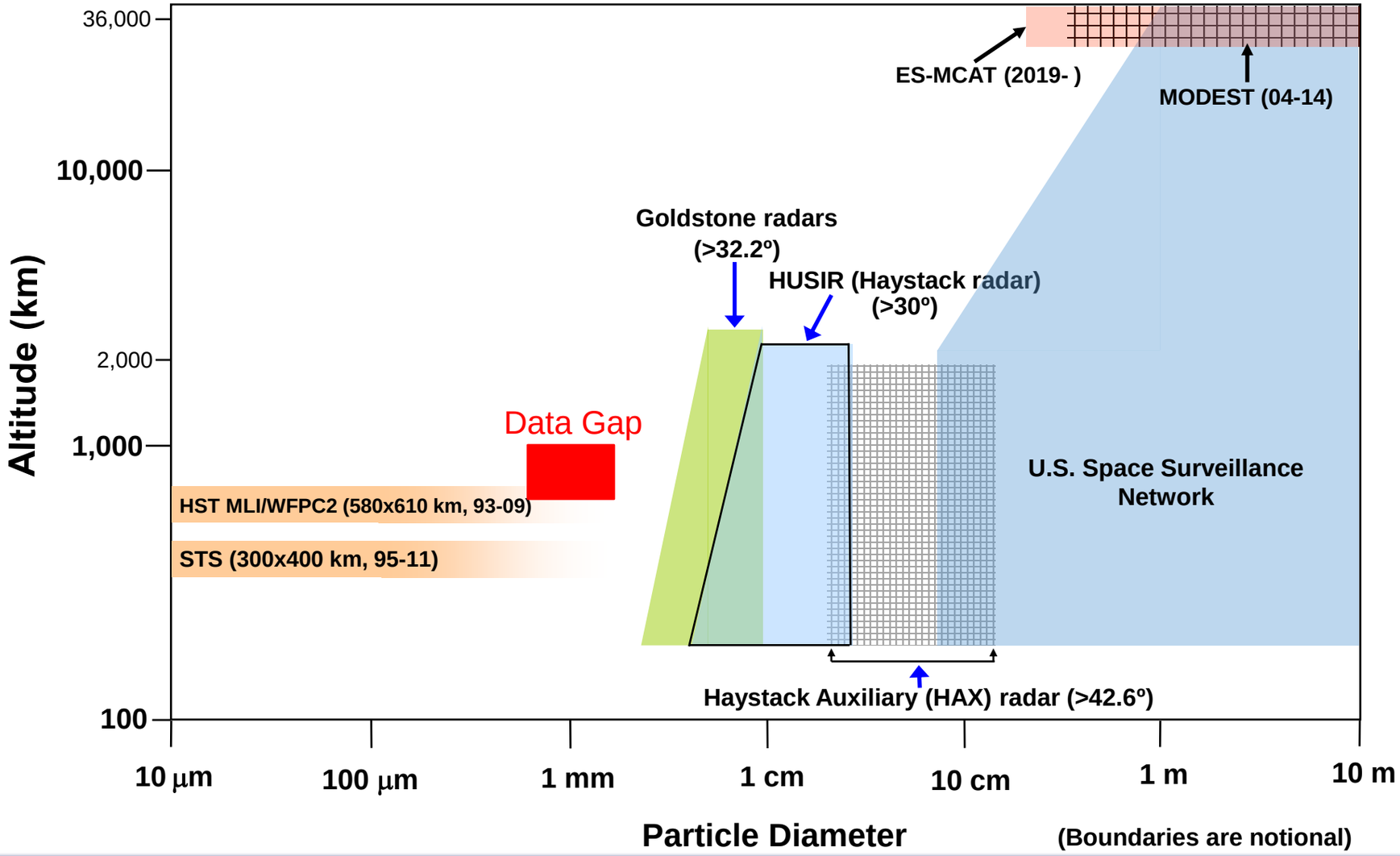
- **An engineering model is a tool used primarily by satellite designers and operators in order to compute the mission risk to their vehicles from orbital debris impacts**
  - NASA's Orbital Debris Engineering Model (ORDEM) provides information on debris impact rate as a function of size, material density, and impact speed and direction
    - Latest version is ORDEM 3.2, released in March 2022
  - The orbital debris risk computed by an engineering model is different than the risk computed for a satellite conjunction
    - ORDEM computes long-term impact risk as probabilities
    - ORDEM covers debris sizes too small to be tracked
      - **Mission-ending risk is dominated by small, untracked debris**
- **Since the orbital debris environment is dynamic, ORDEM must be updated periodically to better reflect reality**

# Optical Data Sources for ORDEM

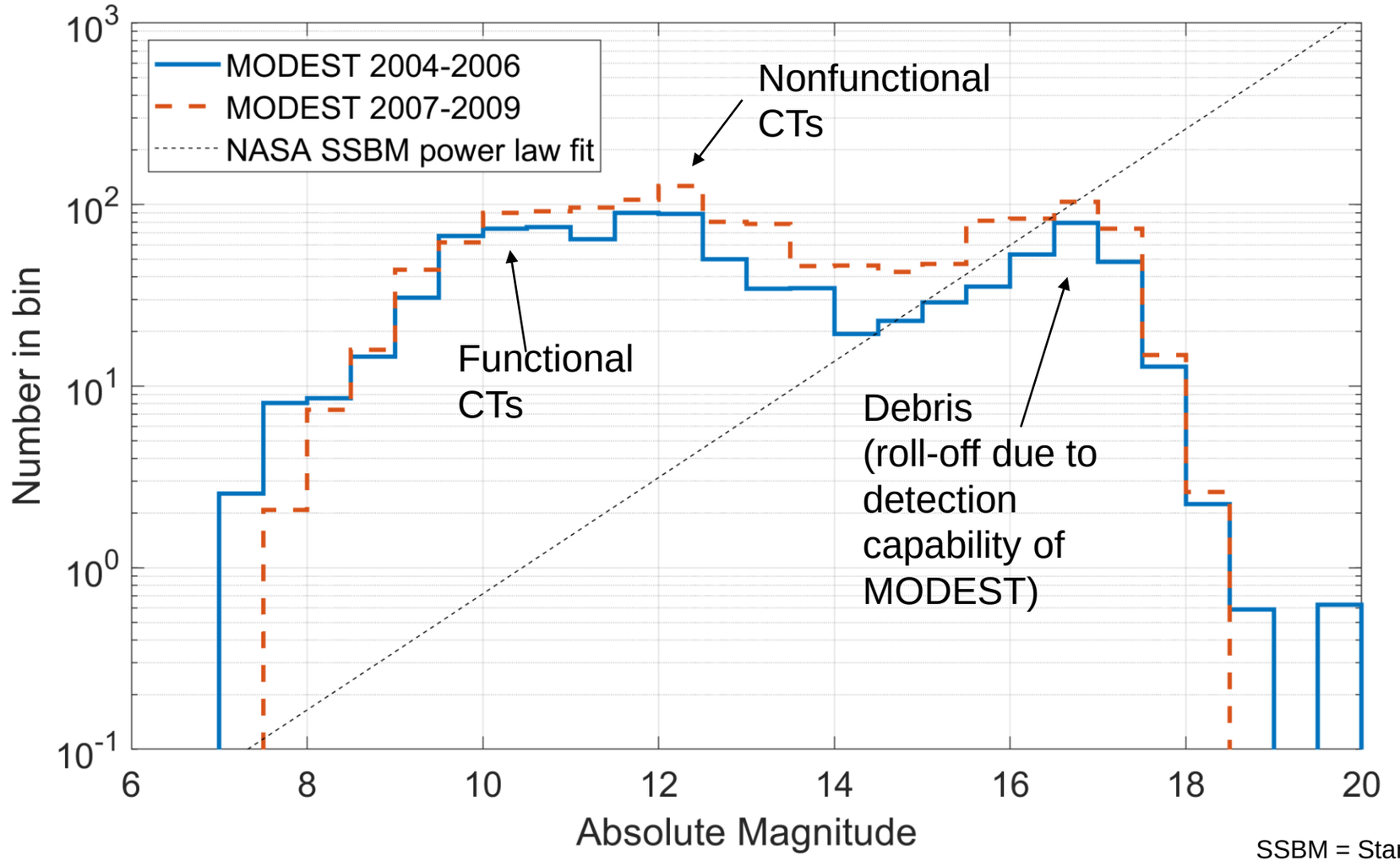



- **SSN catalog**
  - Nearly complete for objects down to approximately 10 cm in LEO and 1 m in GEO
- **Michigan Orbital DEbris Survey Telescope (MODEST)**
  - Provides statistical GEO population for ORDEM below 1 m
  - 0.6 m telescope located at Cerro Tololo Inter-American Observatory
  - Primary optical source for NASA from 2001-2014
  - Data is correlated with SSN catalog
    - Correlated Targets (CTs) and Uncorrelated Targets (UCTs)
  - Assumed circular orbits (eccentricity = 0, circular mean motion)
  - Datasets covering 2004-2006 and 2007-2009 were used for building the ORDEM 3.1 GEO population
  - Dataset covering 2013-2014 was used for ORDEM 3.1 validation

# Data Coverage



# MODEST Magnitude Distribution




SSBM = Standard Satellite Breakup Model

# GEO Debris Ring Filter (1/2)

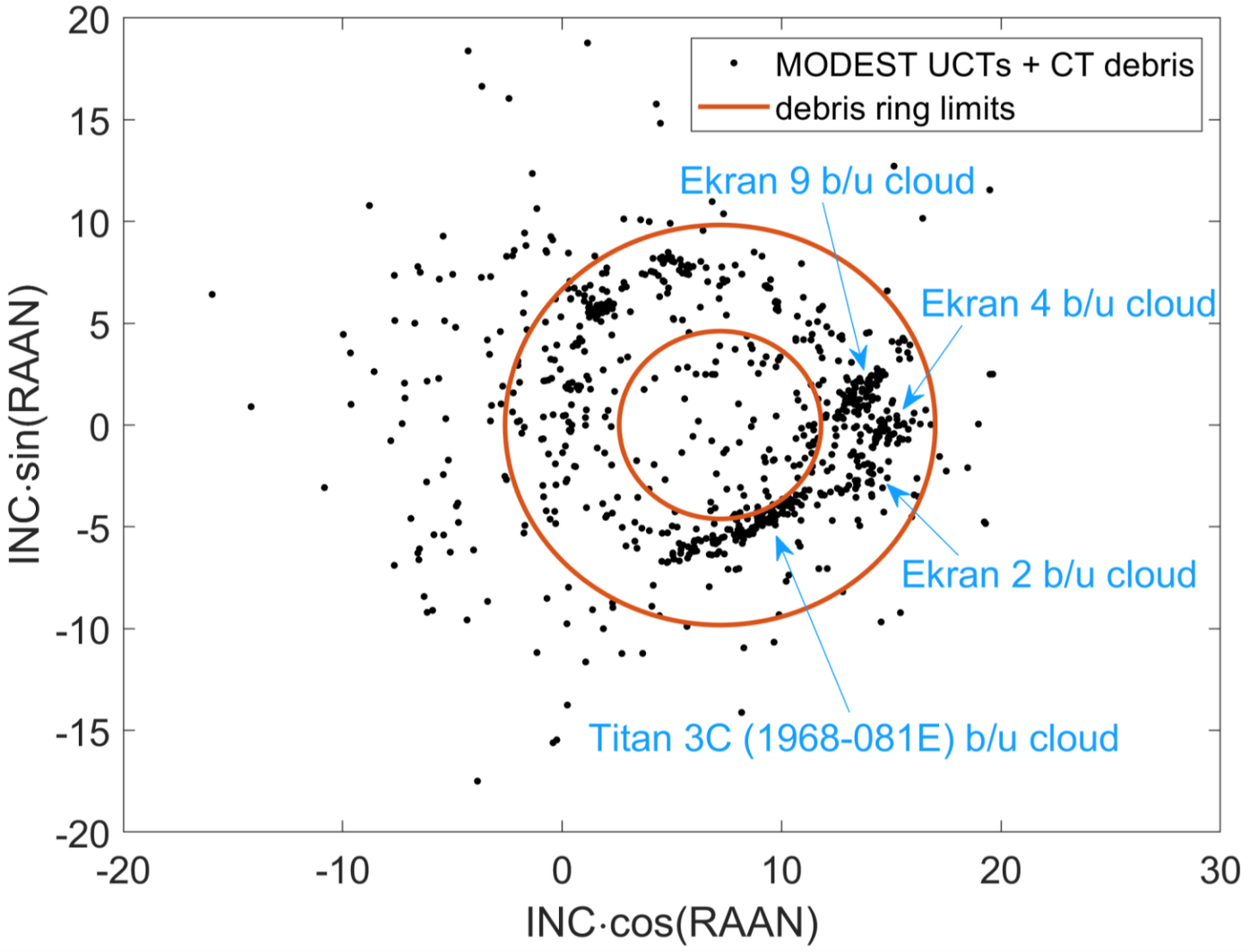
- **GEO debris ring used to filter data for fragmentation debris**
  - Non-GEO objects may be misclassified as GEO objects due to the short-time arc for GEO observations and the circular orbit assumption
  - Uncontrolled objects in GEO naturally precess in inclination / right ascension space, follow a loop in Cartesian coordinates of

$$(INC \cdot \cos(RAAN), INC \cdot \sin(RAAN))$$

$INC$ = inclination
$RAAN$ = right ascension of the ascending node

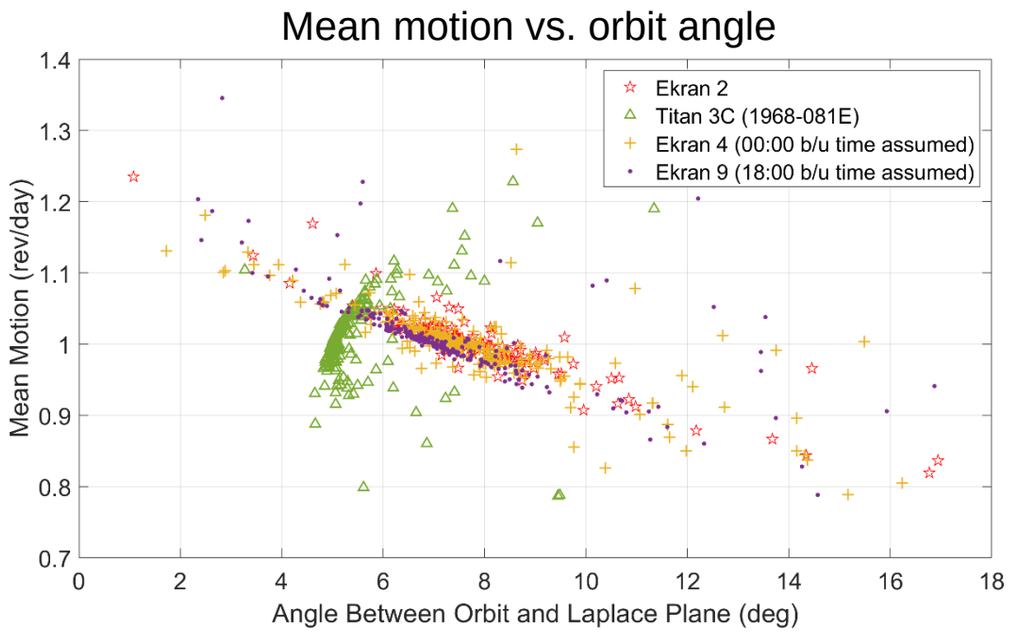
  - Controlled, intact objects tend to clump near (0˚,0˚) while derelict intact satellites and debris tend to spread out
  - Orbit angle = angle between object's orbit and stable Laplace plane used to identify objects within the debris ring

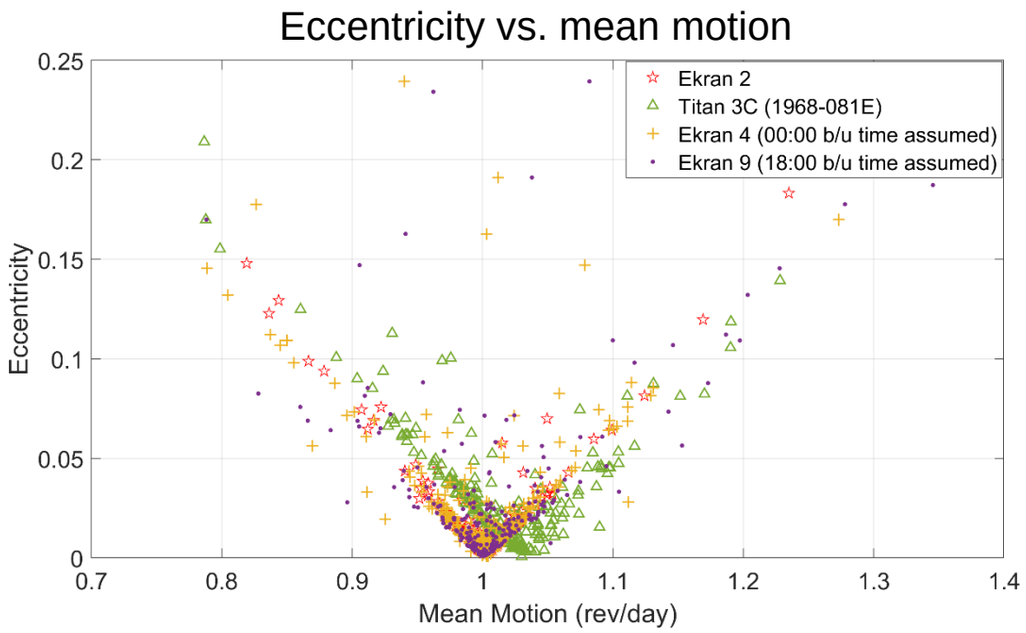
# GEO Debris Ring Filter (2/2)



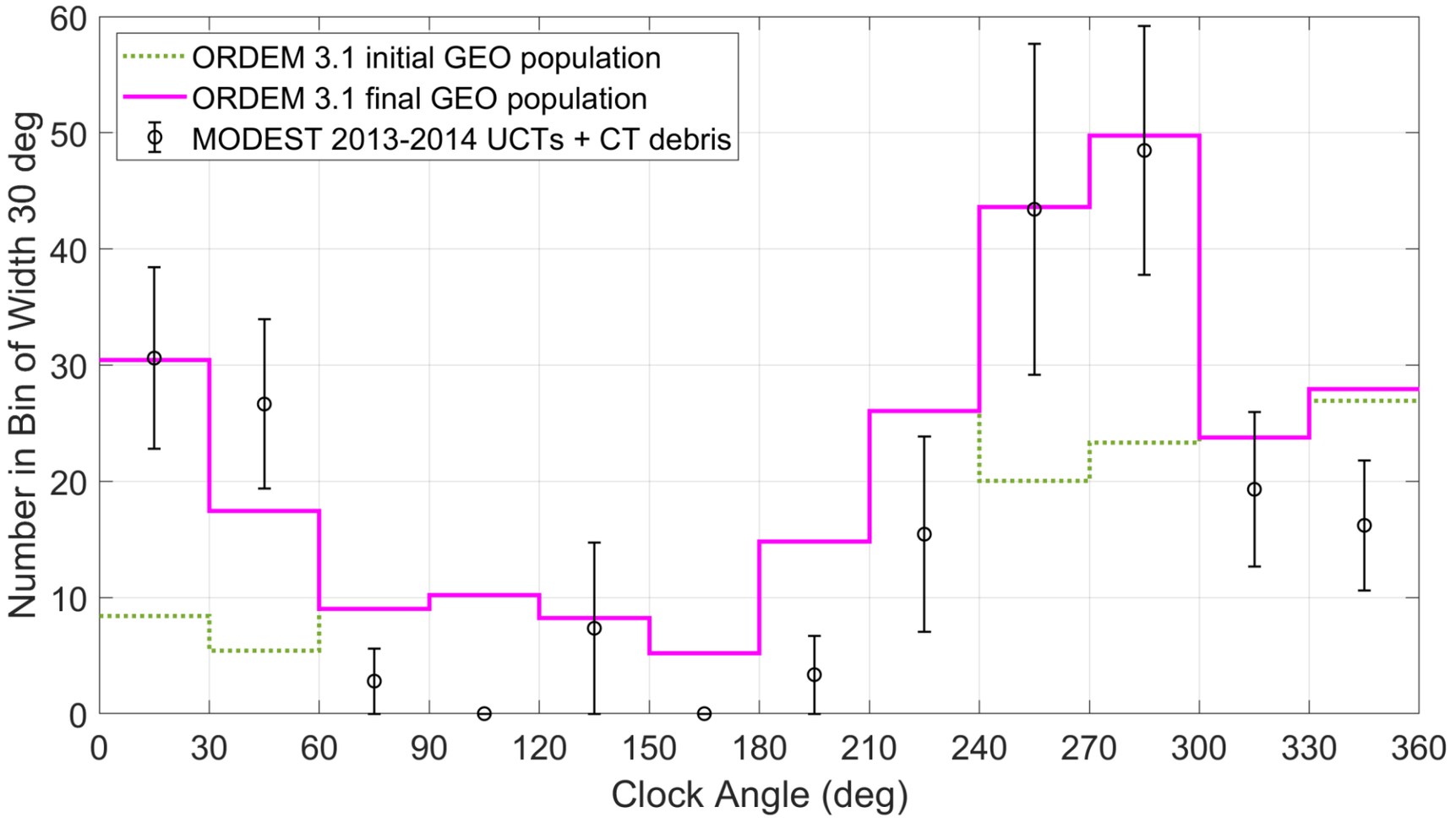
# Assigning Non-Circular Orbital Elements

- **Circular orbit assumption is made for MODEST UCTs**
- **Non-circular orbital elements (eccentricity and mean motion) sought to obtain a more realistic orbit**
  - Based on modeled breakup events using NASA SSBM

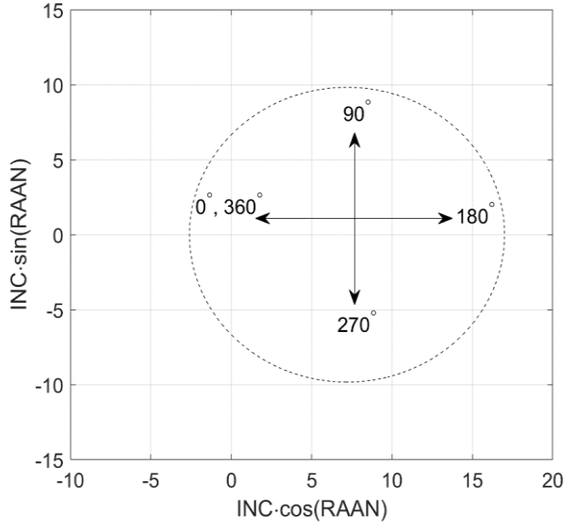


# GEO Population Validation: Clock Angle Distribution




Clock angle defined as angle in $(INC \cdot \cos(RAAN), INC \cdot \sin(RAAN))$

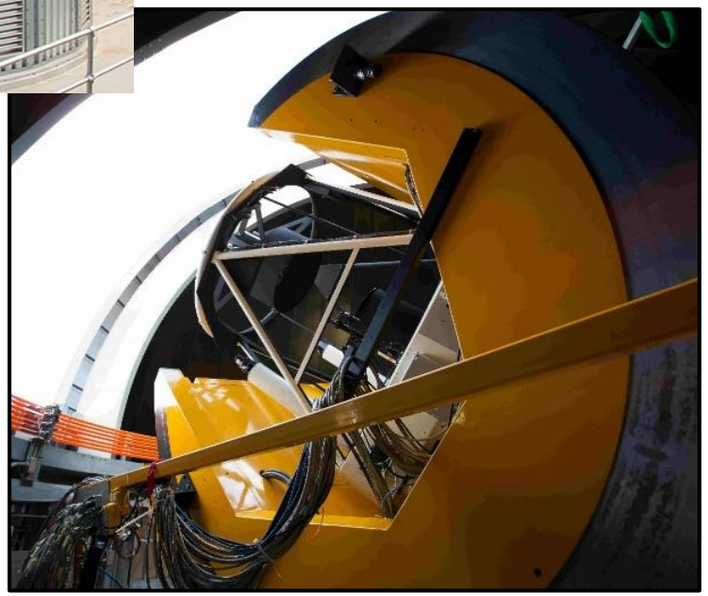



Initial comparisons showed more objects in MODEST dataset in clock angle range 0-60º and 240-300º
→ added simulated breakups to represent unconfirmed GEO breakups

# New Assets: ES-MCAT Overview

- **Eugene Stansbery Meter-Class Autonomous Telescope (ES-MCAT)**
  - 1.3-m, f/4, DFM Engineering fast-tracking optical telescope paired with an ObservaDome fast-tracking dome to accommodate tracking debris at all orbital altitudes
    - Field of View: 0.68 degrees x 0.68 degrees, 0.96 degrees diagonal
    - Limiting Magnitude: 19.48 ± 0.18 (estimated from data for primary mirror in good condition in r')
    - Current limiting magnitude: 16.63 ± 0.285 (g' prime, current condition 01/01/2022 and 03/14/2022)
  - Deployed on Ascension Island (7° 58' S, 14° 4' W, 350' El)
    - Joint NASA-Air Force Research Labs (AFRL) project, located on the U.S. Space Force base (45th Space Wing, Detachment 2 near the Ascension Auxiliary Air Field)
  - Its near equatorial latitude ensures that low-inclination LEO, GEO, and GEO transfer orbit (GTO) target orbits pass overhead (less atmosphere to see through and ability to view all orbit inclinations)

Credit: Ben Hanna



# ES-MCAT Milestones

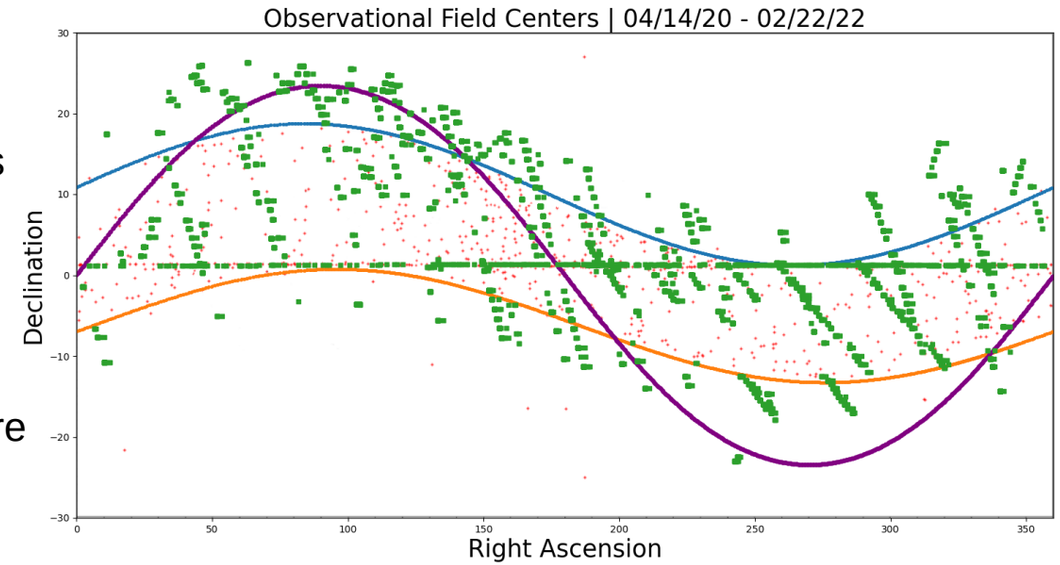
- **Milestones**
  - Concept development (2000 - 2003)
  - Groundbreaking on Ascension (2014)
  - First-light (2015)
  - URR (2017)
  - IOC (2019)
  - FOC (7 September 2021)
    - Proven autonomous capability to safely acquire/process GEO survey data
    - Characterized astrometric and photometric uncertainties using the GAIA catalog
    - Transmit results to NASA/JSC
  - First GEO survey completed (2022)

# GEO Survey Approach

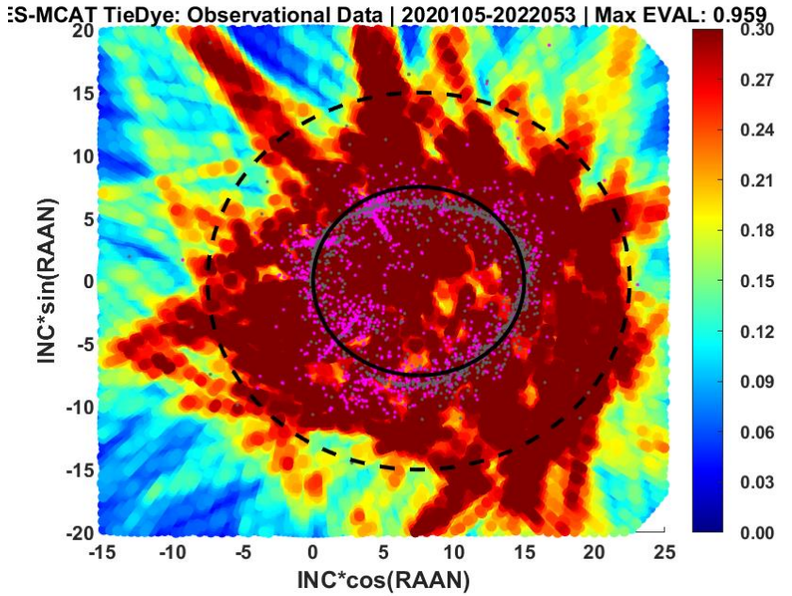
- **Survey Method**
  - Avoid week around full moon
  - Otherwise point anti-solar, to maximize illumination
    - 1-h in HA/RA leading/trailing the Earth's shadow
    - Declination decreases by -0.5 degrees each night until minimum Declination is hit (5 deg below GEO belt)
    - Results in a diagonal path
- **Daily motion for GEO Belt objects at Ascension**

**Purple** Line represents Earth Shadow trail

**Green** squares are Field Centers

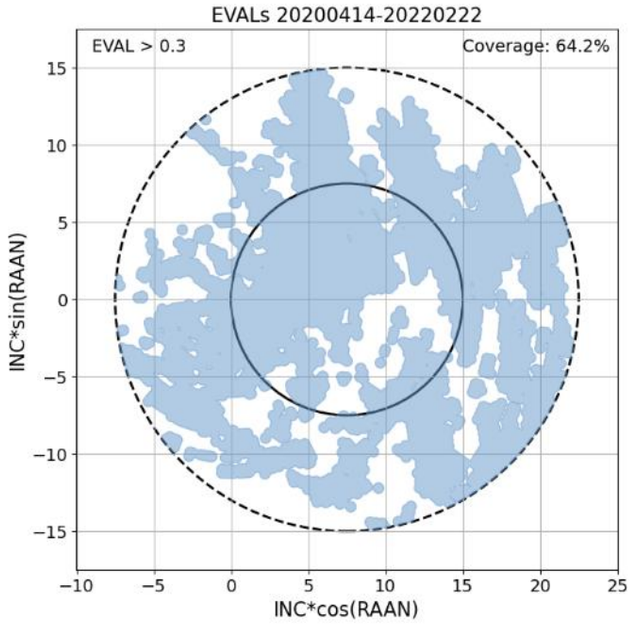


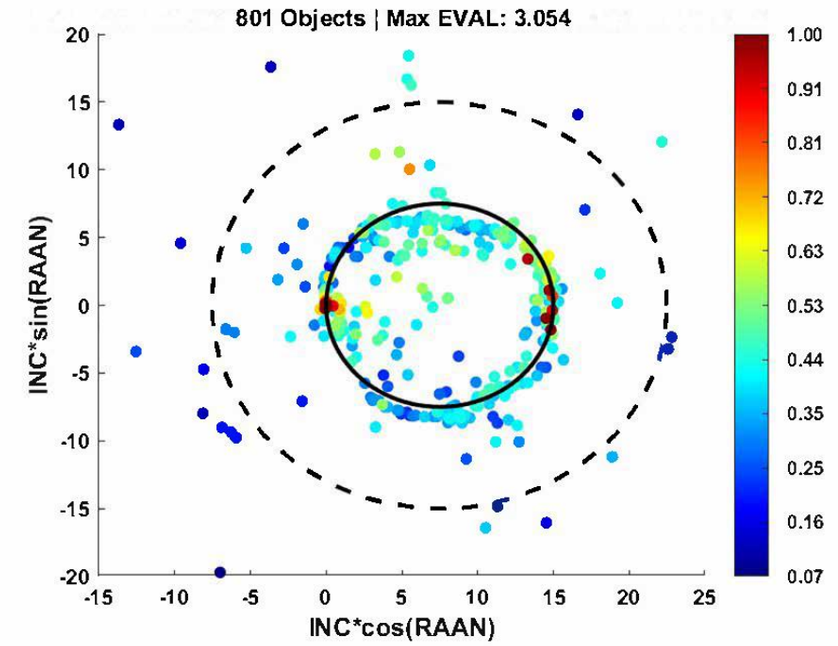

- **A "Complete GEO survey"**
  - Region of Interest – a "donut" area with a diameter between 7.5 and 15 centered at 7.5 INC*sin(RAAN) and 7.5 INC*cos(RAAN)
  - Produces images that can provide an expectation value (EVAL) above threshold (0.3 or 0.2) coverage in the INC/RAAN space of interest.



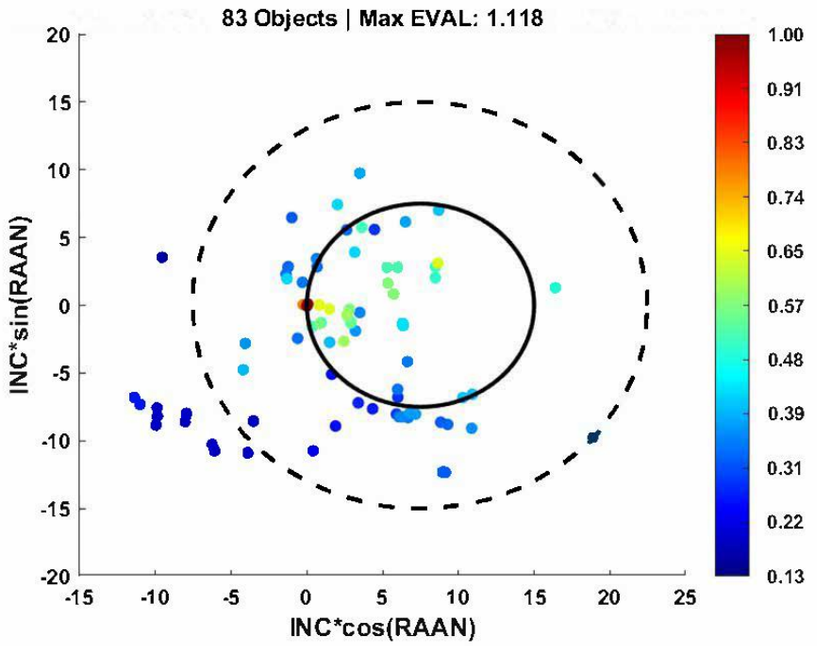

*INC = orbit inclination; RAAN = Right ascension ascending node*

# ES-MCAT's First GEO Survey




CTs




UCTs

# Thank you!

- **Any questions?**